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NOTES ON RESISTANCE MEASUREMENTS IN PLATINUM THERMOMETRY.

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Several years ago an investigation was begun in the Jefferson Physical Laboratory, the object of which was to compare the scale of the constant-volume gas thermometer with that of the platinum-resistance thermometer, more especially at temperatures above 100° C. The intention was to extend the work of M. Chappuis, of the Bureau International des Poids et Mesures, and also to obtain results on the constant-volume thermometer for comparison with those of Messrs. Callendar and Griffiths on the constant-pressure instrument.

Before this was completed the publication of other investigations, particularly those of the Physikalsch Technische Reichsanstalt, made such a research hardly necessary. During the preliminary work, however, problems came up leading to experimental methods which in themselves may be of some interest.

In the standardization of the platinum thermometer the greatest possible refinements are called for in the resistance measurements. Errors peculiar to this instrument arise in correcting for the lead resistance, in avoiding possible cooling effects on the platinum on account of the presence of the comparatively large leads, and also in expressing in terms of some selected coil or unit the value of the platinum resistance.

The elimination of lead resistance is usually accomplished by subtracting the values obtained by direct measurement, or by placing in the stem of the thermometer dummy leads which are connected in the opposite side of a Wheatstone's bridge, the ratio coils of which are equal. The first method necessitates duplicate measurements of great absolute accuracy; the second involves the assumption that the two sets of leads change their resistance equally under all possible conditions, an assumption that can never be proved in any particular case. Moreover, alterations in the leads result in a new thermometer, and prevent to a considerable extent the verification of old measurements.

When either of these methods is used it is an advantage to have the leads of low resistance; this means large wire and the possibility of a great cooling effect of these large leads on the fine platinum wire.

It is the first object of this paper to show a method of bridge connection whereby the resistance of the leads may be entirely and directly eliminated.

A difficulty peculiar to resistance thermometers results from the condition that in general we have to measure a resistance varying over a very great range. The regular form of resistance box presents conditions which make it insufficient for this purpose, involving, as it does, the calibration of resistances which are high multiples and sub-multiples of a chosen standard.

The potentiometer methods of measurement suggested a modification of the Carey-Foster form of the Wheatstone bridge, which was finally adopted. A resistance may be measured by connecting it as part of one side of a wire bridge and tapping the galvanometer lead successively to its two ends. Its value is given by the resistance between the balancing points of the other galvanometer terminal, multiplied by the ratio of the resistances of the two sides of the bridge. This may be modified in the following way, so that only a difference has to be measured: — Let T (Figure 1) be the resistance to be measured, with D and F the leads and external resistance in the bridge construction, S the known resistance, M and N the ratio coils, with a low resistance slide wire between them. The resistance of the two portions of this wire we shall denote by w and w'. The wire between the points 3 and 4 can be neglected for the present. The shaded portions of the figure are thus heavy copper connectors, the resistance of a single one being equal to j.

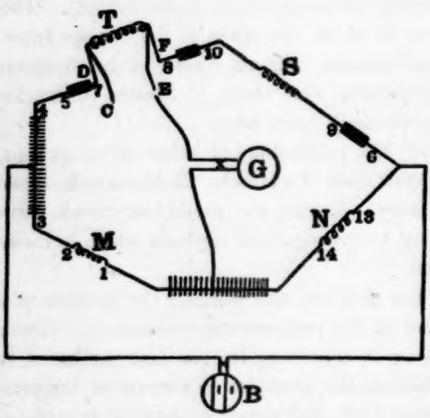

FIGURE 1.

By shifting the galvanometer lead from E to C a large change in the positions of the other galvanometer terminal on the wire is called for.

However, by having the resistance S very nearly equal to T, and by interchanging it and the two connectors between 8 and 10 and between 9 and 6 with the connector between 5 and 7, we nearly neutralize the required change in the balancing point on the bridge wire. The resulting connections are given in Figure 2. (The numbers refer particularly to Figure 3, and will be explained later.)

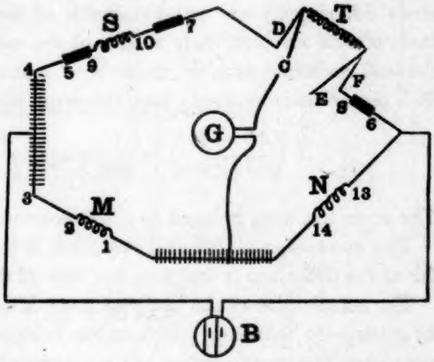

FIGURE 2.

It is then obvious that as a potentiometer method, where each element of the wire measures an element of resistance in the opposite side of the bridge, the resistance (d) of the bridge wire between the balancing points multiplied by the ratio of the resistance of the two sides of the bridge gives the difference between $T+j$ and S.

As a Carey-Foster method the results may be worked out as follows:

$$\frac{T+j+D}{M+w}=\frac{S+F+2j}{N+w'} \text{ (Figure 1).}$$

$$\frac{S+2j+D}{M+w-d}=\frac{T+F+j}{N+w'+d} \text{ (Figure 2).}$$

$$(T+j+D)\,N+(T+j+D)\,w'=(S+F+2j)\,M+(S+F+2j)\,w$$

$$\begin{aligned}(S+2j+D)\,N+(S+2j+D)\,w'+(S+2j+D)\,d \\ =(T+F+j)\,M+(T+F+j)\,w-(T+F+j)\,d.\end{aligned}$$

$$(S+j-T)\,N+M+w+w'=-d\,(S+T+D+F+3j).$$

$$T-(S+j)=d\left(\frac{S+T+D+F+3j}{N+M+w+w'}\right).$$

The lead resistances D and F only appear in the ratio by which the difference d is multiplied. If, by the ordinary method of directly measuring the lead resistance and subtracting, a given percentage error is

introduced, with the above arrangement, one-half the percentage error is introduced as regards the knowledge of the *difference* between S and T. Let us assume that we are comparing two twenty-ohm resistances differing by one two-hundredth of their value (or .1 ohm) with leads of half an ohm each to one of the coils. If we should disregard the lead resistance entirely, an error of 1 ohm or 5 per cent would result with the ordinary method; here the error would be approximately

$$.1\left(\frac{41}{40}-\frac{40}{40}\right)=\frac{1}{400}\text{ ohms, or .012 per cent.}$$

The error has been reduced to one four-hundredth of the other value.

The knowledge of the lead resistance is thus of less importance, in so far as the difference is less than one side of the entire bridge.

The actual value of the lead resistance is determined most satisfactorily by getting the balancing points on the bridge wire with the galvanometer connected first to the end of the platinum wire by means of leads C and E, and second to the ends of D and F, where they connect to the heavy bridge terminals.

The necessary accuracy in the knowledge of the lead resistance being greatly reduced, we are able to have the leads of much higher resistance, and thus decrease greatly the possibility of heat being conducted to or from the platinum by the comparatively heavy low resistance leads.

We have now the problem of arranging a resistance S, whose value in terms of some particular coil can be varied from a fractional part to four or five times the resistance of the platinum at 0° C., and in steps small enough to permit the use of a low resistance bridge wire. A box of series resistances introduces calibration problems that are sure to give trouble, especially when some of the resistances bear a ratio to the unit of 100 : 1 or 1000 : 1.

A simple and more direct method, but yet more tedious as regards computation, is to arrange a set of five, ten, and twenty-ohm coils (whose values in terms of a ten-ohm unit can be determined with great convenience and accuracy) in series and parallel combinations the resistances of which increase in steps of .1 or .05 ohms from two or three, to thirty or forty ohms. The resistance of any complicated combination can be computed with a little care, and the errors are especially small, as they depend upon the comparison of coils in the ratio of 2 : 1 instead of 100 : 1.

As finally built the bridge consists (Figure 3) of copper bars and forgings 19 × 14 mm. in cross section, supported on a board of first-

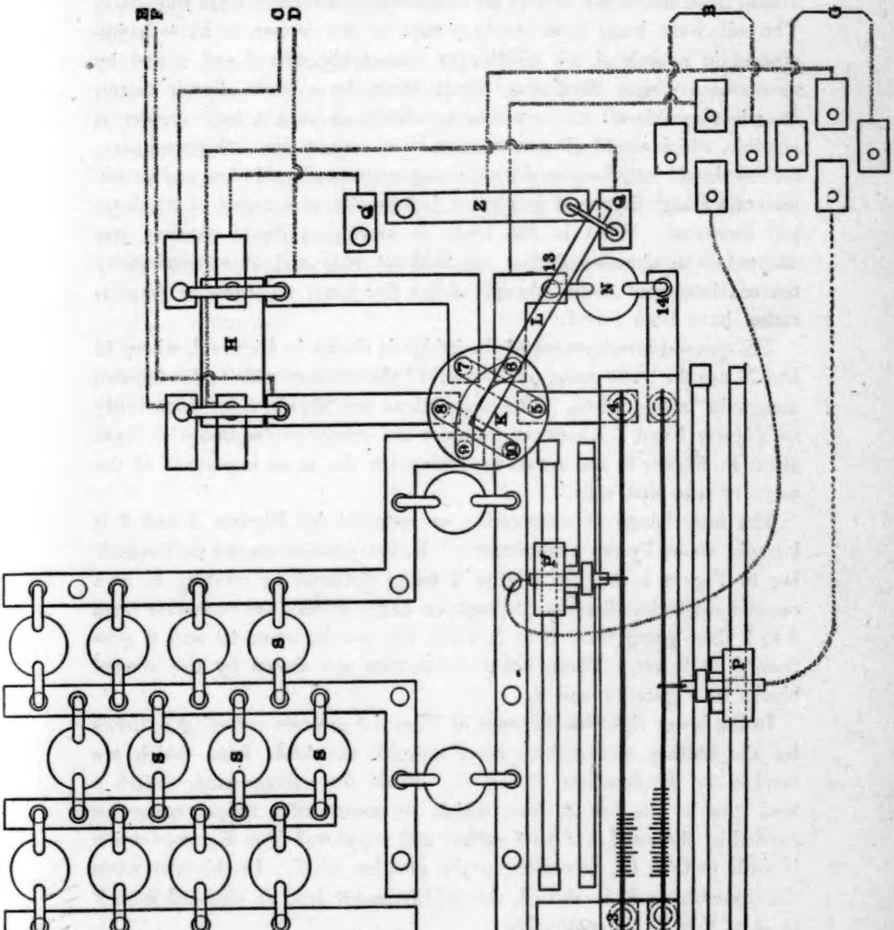

FIGURE 3.

quality cherry, 66 cm. long and 61 cm. wide, with hard-rubber bushings 7 mm. thick under the bars to give satisfactory clearance from the board. The coils were hung from mercury cups in the copper, so as to be immersed in a tank of oil, which was thoroughly stirred and mixed by means of a simple circulating pump driven by a small electric motor. In selecting this oil the aim was to obtain as pure a hydrocarbon as possible, which would give no trouble from evaporation. A pure hydrocarbon should introduce no difficulties on account of oxidation, and should maintain a high degree of insulation indefinitely as a result of its chemical inertness. What in the trade is known as liquid vaseline was adopted — an almost colorless oil, without odor and of approximately the consistency of a thin syrup. After five years no traces of deterioration have been found.

The general arrangement of the bridge is shown in Figure 3, where M and N are the ratio coils, and P and P′ the contact makers for the two manganin bridge wires. The connections are shown diagrammatically on Figures 1 and 2, where the numbers and letters correspond with those given in Figure 3, and serve to distinguish the most important of the mercury cups and coils.

The interchange of connections as required by Figures 1 and 2 is brought about by the "commutator" K, the position shown corresponding to Figure 1, that for Figure 2 being obtained by rotating K in a counter-clockwise direction through an angle of 60°, the connector from 5 to 7 then going from 6 to 8, while the one between 10 and 8 goes from 5 to 9, etc. These heavy connectors are shown by the shaded blocks in Figures 1 and 2.

In the lower right-hand corner of Figure 3 are two reversing switches for the battery and galvanometer circuits, the leads from which are marked by the brackets B and G. From the galvanometer switch a lead runs to the bar Z, from which, by means of a copper connector carried by the rod L (of hard rubber and supported from K), connection is made to Q or Q′, according to the position of K. In this way when the commutator K is shifted, the galvanometer lead is changed from F to D or E to C automatically.

The throw-over switch H allows the galvanometer lead coming from Q or Q′ to connect either to the ends of the platinum wire by means of C and E, or to the ends of the leads D and F. Readings made in this latter case give data as stated above to determine the resistance of the main leads to platinum thermometer T. (Figure 3 shows H thrown to give the connections for determining lead resistance.)

The subsidiary wiring for the galvanometer and battery circuits around the bridge consists of ordinary "flexible cord" drawn into soft rubber tubing.

In the upper left-hand corner of the plan the coils S of accurately known resistance, but approximately 5, 10, and 20 ohms in value, are indicated. These are connected to give roughly the resistance of T, and the desired difference is obtained from the wire readings.

The second wire, shown between mercury cups 3 and 4, is used for calibrating the standard wire, and for bringing the readings of P to convenient portions of the scale.

The entire bridge is kept under cover and operated from the outside by cords and simple levers, so far as the actual readings on the bridge wire are concerned.

Jefferson Physical Laboratory,
Harvard University,
Cambridge, Mass.